Modeling and Analysis of Structural Dynamics for a One-Tenth Scale Model NGST Sunshield

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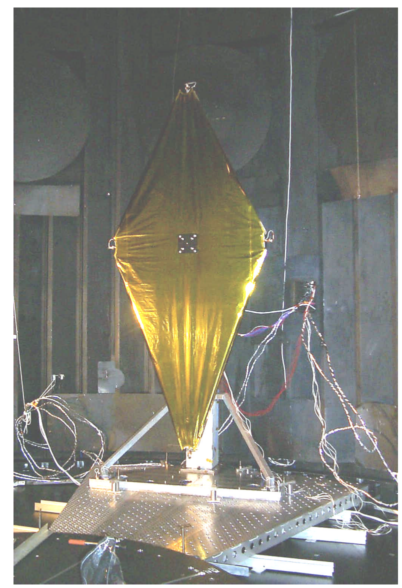
Overview

- Introduction
- Membrane Modeling
- Finite Element Model
- Analysis of Sunshield Dynamics
  - Modal Analysis
  - Impulse Test Simulation
- Comparison of Analysis and Experiment
- Closing Remarks

Introduction

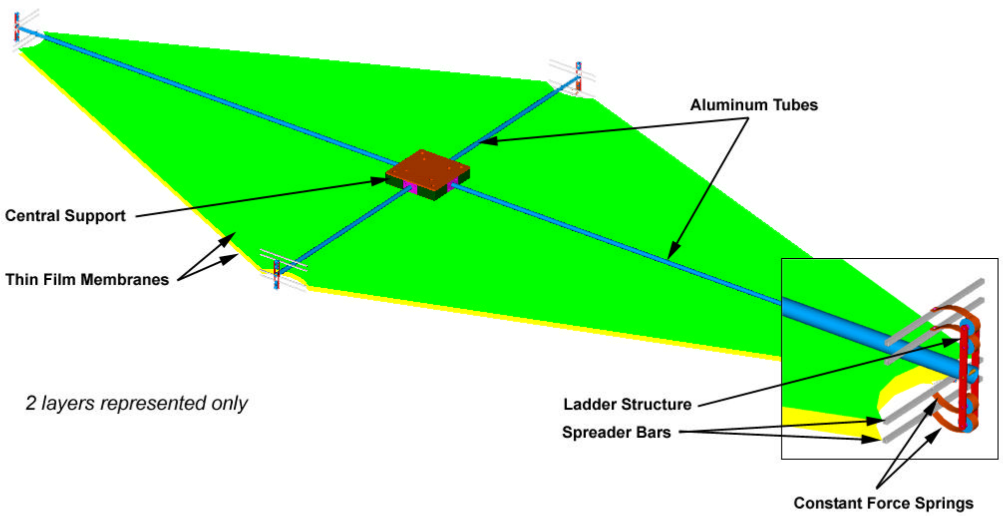
- The Next Generation Space Telescope (NGST) will require a lightweight, deployable sunshield to provide passive cooling for optical systems.
- NGST ‘yardstick’ concept sunshield characteristics:
  - Central support structure
  - Deployable support booms
  - Pretensioned, thin-film membranes
- Technology development needs:
  - Modeling and Analysis
    - High confidence, test validated structural models to predict potential disturbances to observatory due to sunshield dynamics
    - Assessment of membrane wrinkling effects
  - Testing
    - Scale model testing methodologies
    - Advanced, non-contact instrumentation
- Analysis and ground testing of a one-tenth scale model of the NGST ‘yardstick’ concept sunshield is being carried out to develop and validate capabilities to predict and verify sunshield structural characteristics.

NGST ‘Yardstick’ Concept



One-Tenth Scale Model Sunshield Ground Test Article

One-Tenth Scale Model NGST Sunshield



Test Article Characteristics:

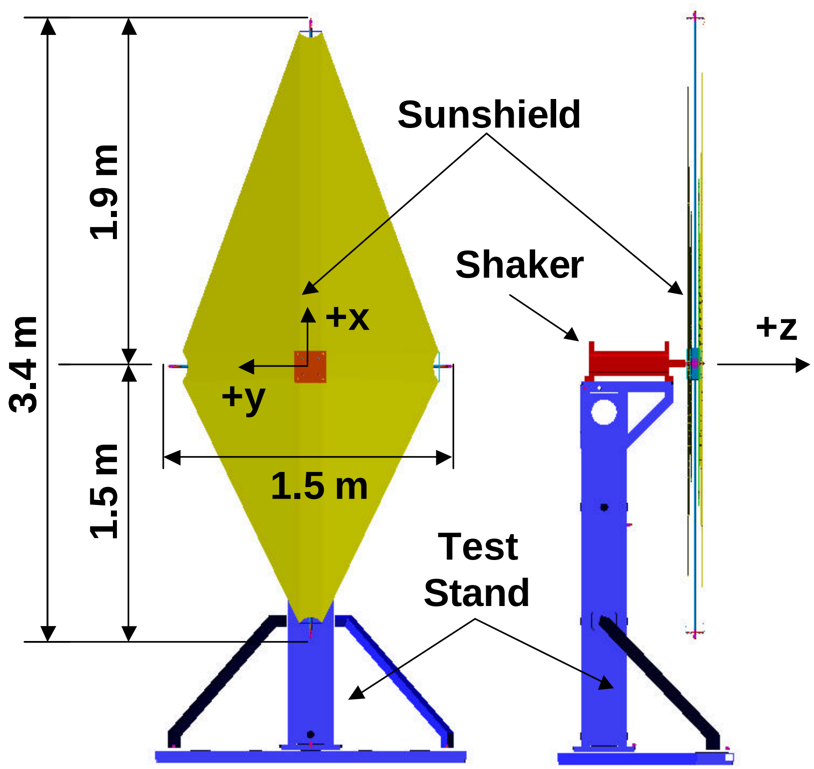
Overall size: 3.4 m x 1.52 m

Membranes: 4 layers of 13 micron (0.5 mil) Kapton

Support booms: Aluminum tubes

Membrane preload: 1.425 N (0.32 lbs) per corner

Schematic of Test Setup with Sunshield in Short Side Down Orientation



Sunshield Dynamic Tests

- Dynamic testing of the one-tenth scale model NGST sunshield in a vacuum environment was completed in August 2000 at NASA GSFC.

- Test objectives:
  - Determine the dynamic characteristics of the sunshield (frequencies, mode shapes, and damping) in order to provide data for model validation studies.
  - Verify the planned on-orbit test methodology for the Inflatable Sunshield In Space (ISIS) flight experiment.
  - Characterize the linearity of the system.
  - Characterize the influence of gravity.

- Types of tests:
  - Random excitation tests
  - Impulse excitation tests
  - Sine dwell tests

- Instrumentation:
  - Accelerometers
  - Force transducers
  - Laser vibrometer

Membrane Modeling

- A challenging aspect of sunshield analysis is modeling the behavior of partially wrinkled thin-film membranes.

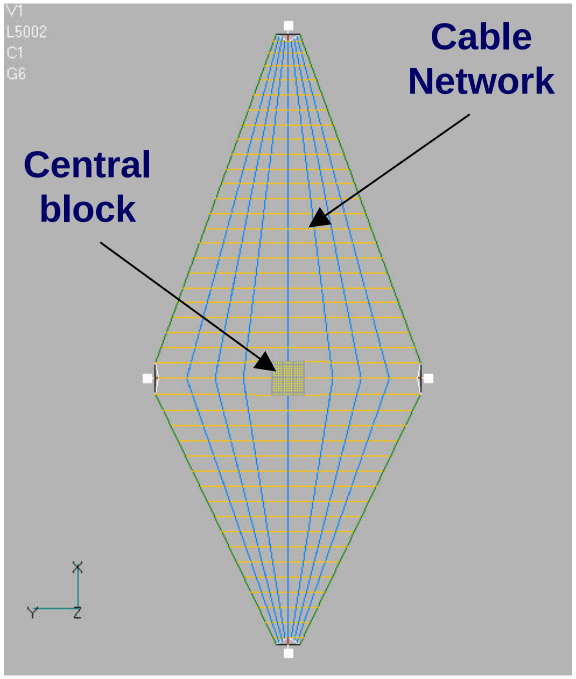
- Finite element modeling techniques for membranes:
  - Standard elements formulations:
    - Ignore membrane wrinkling
    - Numerical problems may occur
  - Cable network method:
    - Approximate/engineering approach for modeling wrinkled membranes
    - Based on the established principal that load transfer in wrinkled regions takes place along wrinkle lines
  - Advanced techniques:
    - Use of tension field theory and special material models to account for wrinkling effects on membrane stress distributions.
    - ‘Fine-scale’ analysis of wrinkling enables the prediction both stress distribution and wrinkling details (wrinkle amplitude, wavelength, etc).

- The one-tenth scale model NGST sunshield finite element model utilized in the current study was developed using the cable network modeling approach.

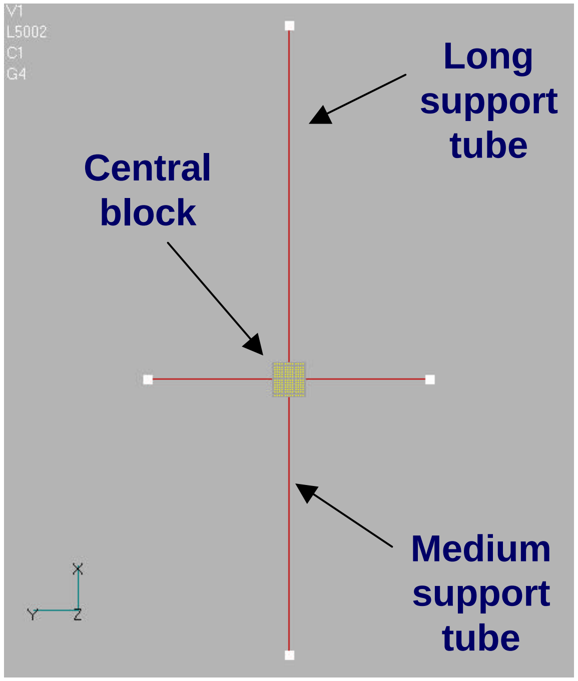
Finite Element Model

- Partially wrinkled, thin-film membranes modeled using ‘cable network’ technique
  - Developed by M. Mikulas/University of Colorado-Boulder
  - Implemented in UAI NASTRAN by S. Lienard at NASA GSFC
- Central block, support tubes, and tip hardware modeled using standard techniques
- Base-drive shaker support condition modeled (0.4 Hz rigid body translational mode of sunshield)

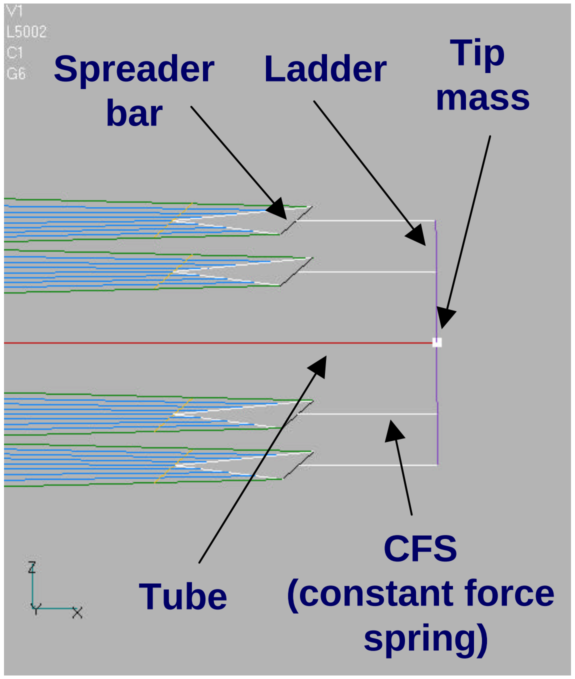
Full FEM



Support Structure



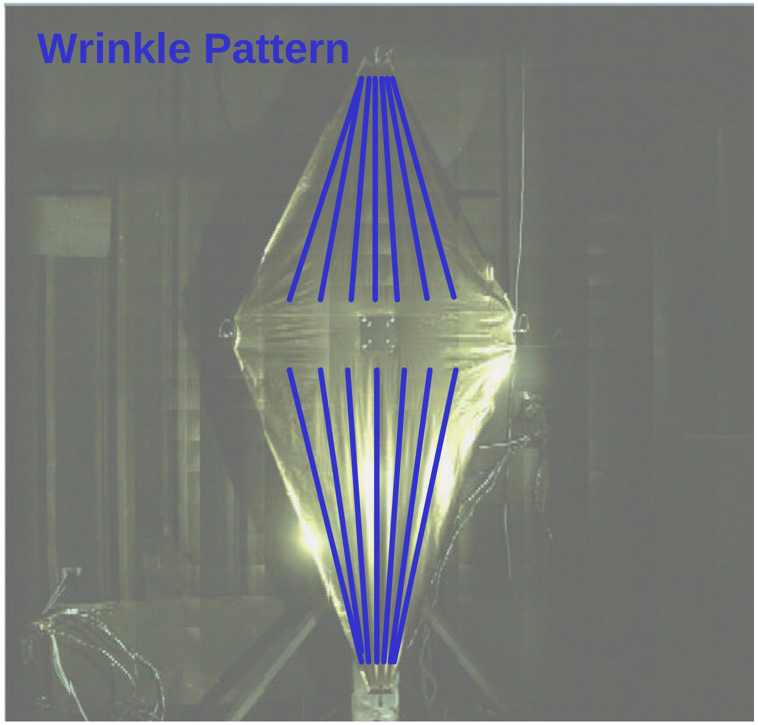
Tip Hardware

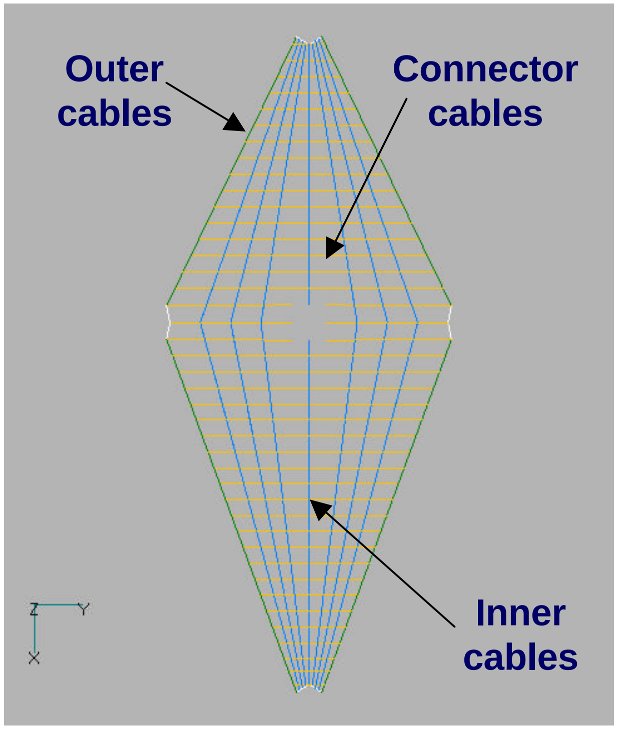


Membrane Cable Network

- The wrinkle pattern in the longitudinal direction is dominant
  - 10 psi longitudinal stress
  - 5 psi lateral stress

- The membrane is meshed with a network of preloaded 'cables' mapped to the wrinkle pattern of the structure.
  - Longitudinal cables are oriented along the wrinkle pattern (load path)
  - Transverse cables act as a connection between cables and represent the mass distribution
  - Approximate representation of the load paths and mass distribution in the structure





Analysis of Sunshield Dynamics

- Finite element analysis of the sunshield was completed using UAI NASTRAN (Version 20.1).

- Nonlinear static analysis
  - Preloads due to constant force springs
  - Gravity loading
  - Export stiffness matrix

- Modal analysis
  - Import stiffness matrix from nonlinear static analysis
  - Calculate frequencies and mode shapes
  - Calculate modal effective mass

- Other dynamic analyses
  - Frequency Response
  - Transient Response (Impulse test simulation)

Modal Analysis Results

- UAI NASTRAN Normal Modes Analysis (SOL 3)

- Modal analysis completed for the following cases:
  - CFS preloads only
  - CFS preloads + Gravity loading with short side down orientation (-X direction)
  - CFS preloads + Gravity loading with sunshield in long side down orientation (+X direction)

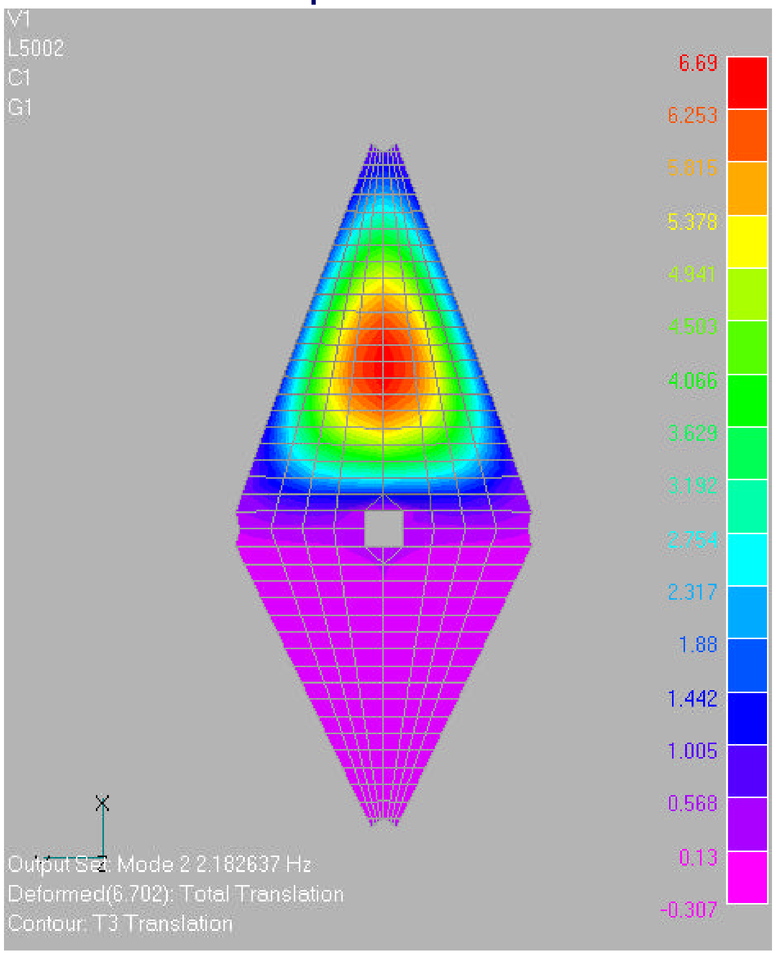
- Effective mass (EFFM) calculations used to select ‘significant’ sunshield modes

Mode	**No Gravity**		**Gravity Short Side Down**		**Gravity Long Side Down**		**Description**
	Frequency (Hz)	**EFFM (%)**	**Frequency (Hz)**	**EFFM (%)**	**Frequency (Hz)**	**EFFM (%)**	
A	2.54	16.0	2.18	9.67	2.61	17.73	Long side of all membrane layers moving in-phase.
B	3.33	5.5	3.33	11.05	2.81	0.39	Short side of all membrane layers moving in-phase.
C	3.66	46.6	3.55	41.32	3.67	48.05	First long tube bending mode
D	5.51	4.9	4.71	3.64	4.79	4.31	Membrane/tube interaction mode
E	5.71	12.8	5.54	14.54	5.55	13.27	First medium tube bending mode
F	6.63	5.9	6.43	9.49	6.32	8.91	Membrane/tube interaction mode

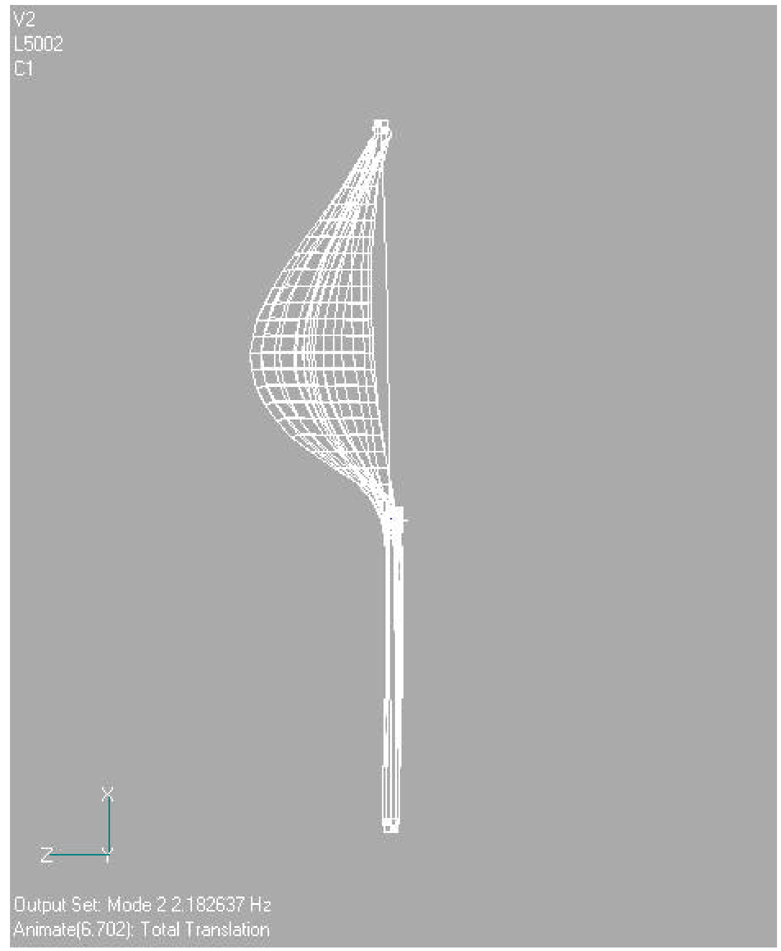
Modal Analysis Results – cont.

First Mode of Long Side of Membranes (F = 2.2 Hz)
Test article orientation = Short side down

Contour Plot of Out-Of-Plane Displacements



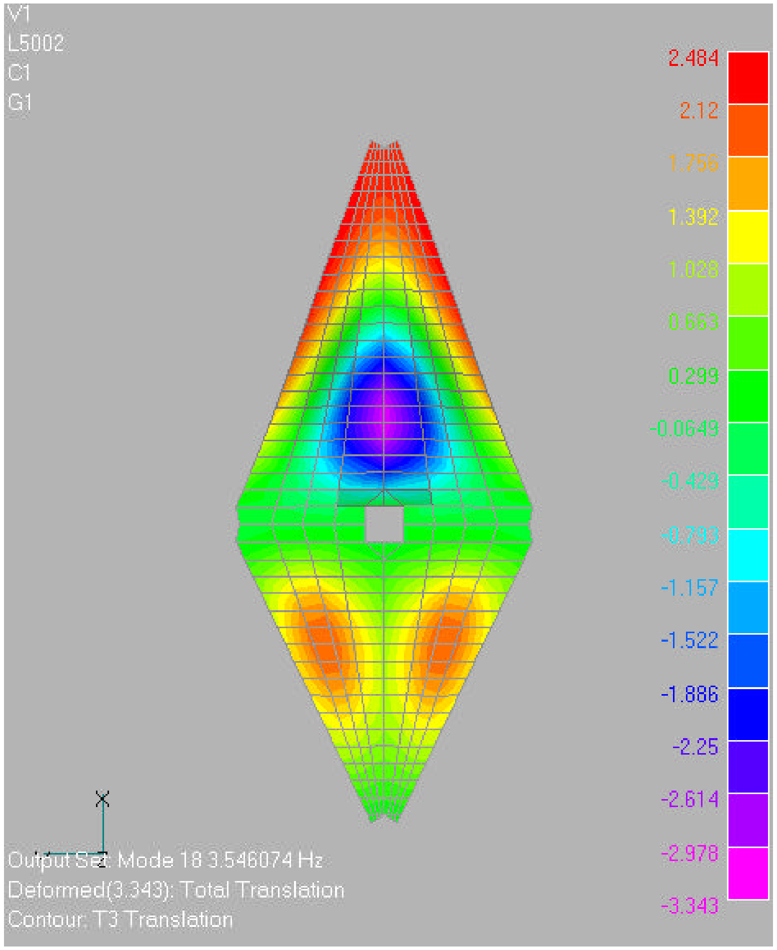
Mode Shape Animation



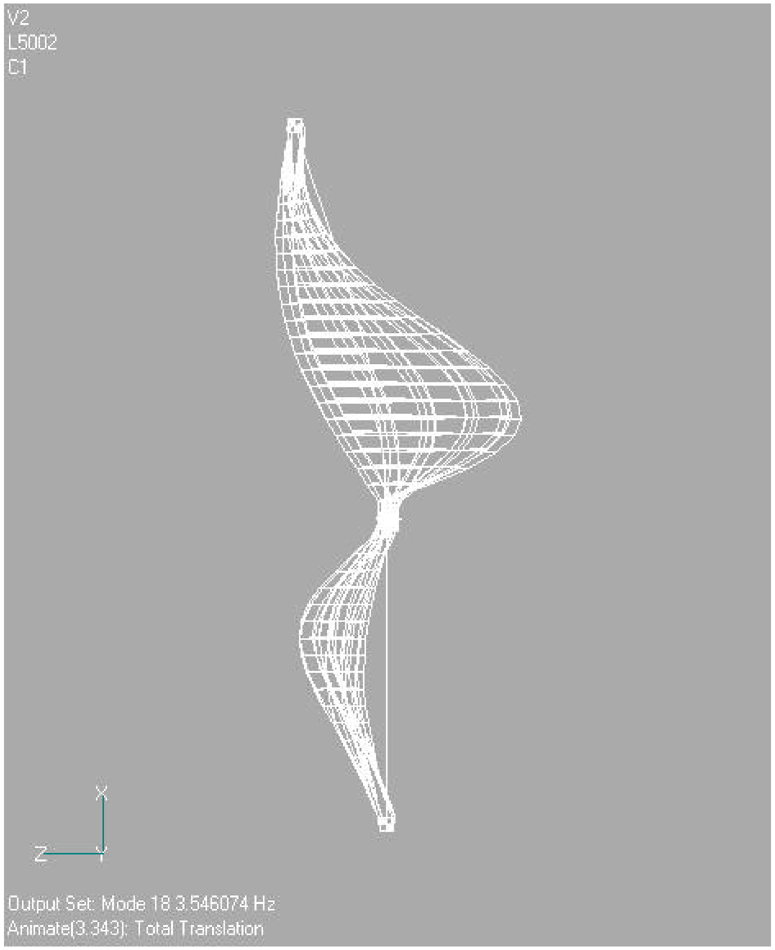
Modal Analysis Results – cont.

First Bending Mode of Long Tube (F = 3.5 Hz)
Test article orientation = Short side down

Contour Plot of Out-Of-Plane Displacements



Mode Shape Animation

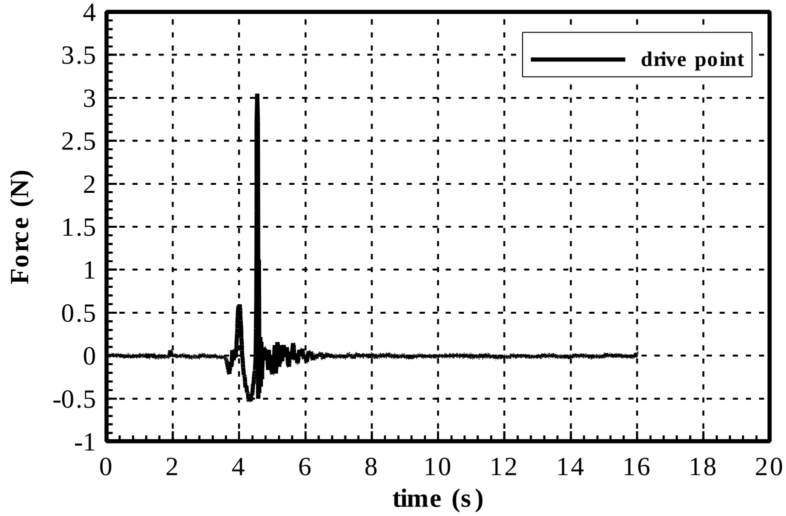


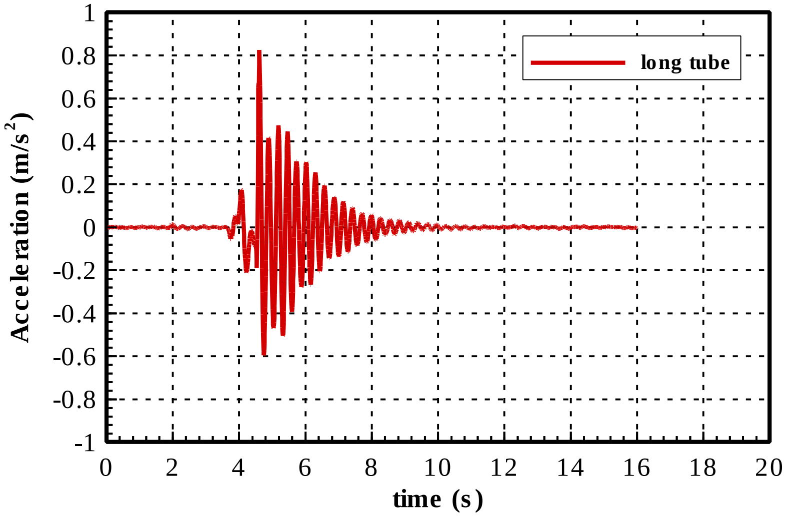
Impulse Test Simulation

- UAI NASTRAN Transient Response Analysis (SOL 12)
  - Modal Method (0 – 10 Hz frequency range)
  - Modal damping (using test-derived damping values)
  - Timestep = 0.0078125 s, Number of timesteps = 2048 , Total time = 16.0 s
- Loading:
  - Static: CFS preloads, gravity
  - Dynamic: force time history at shaker/sunshield interface from ground tests
- Time domain results recovered at key locations:
  - Accelerometers
  - Laser vibrometer measurement points
  - Force transducer at shaker/sunshield interface
- Frequency domain results calculated during post-processing using MATLAB
  - Power spectral densities
  - Transfer functions
    - Input = Applied load at shaker/sunshield interface
    - Output = predicted response at accelerometer, laser measurement locations

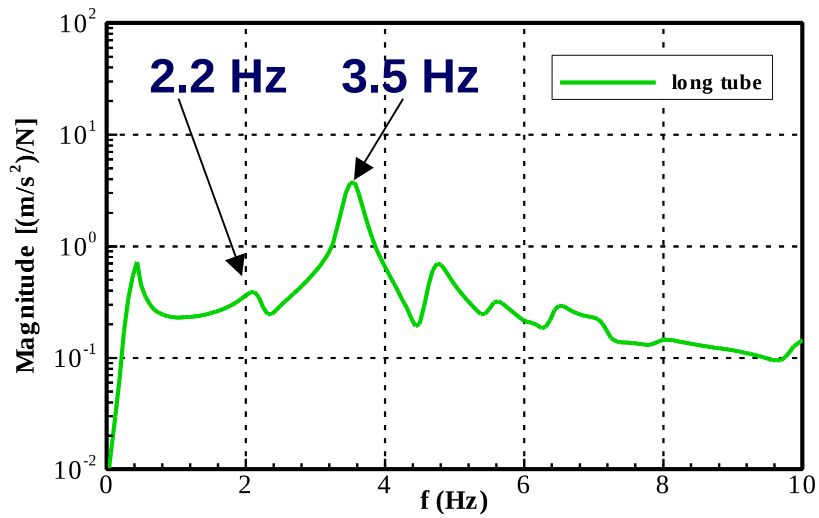
Impulse Test Simulation Results

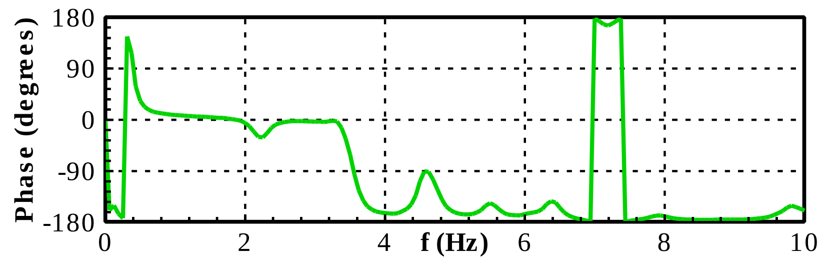
Time Domain Results





Frequency Domain Results





Comparison of Analysis and Experiment

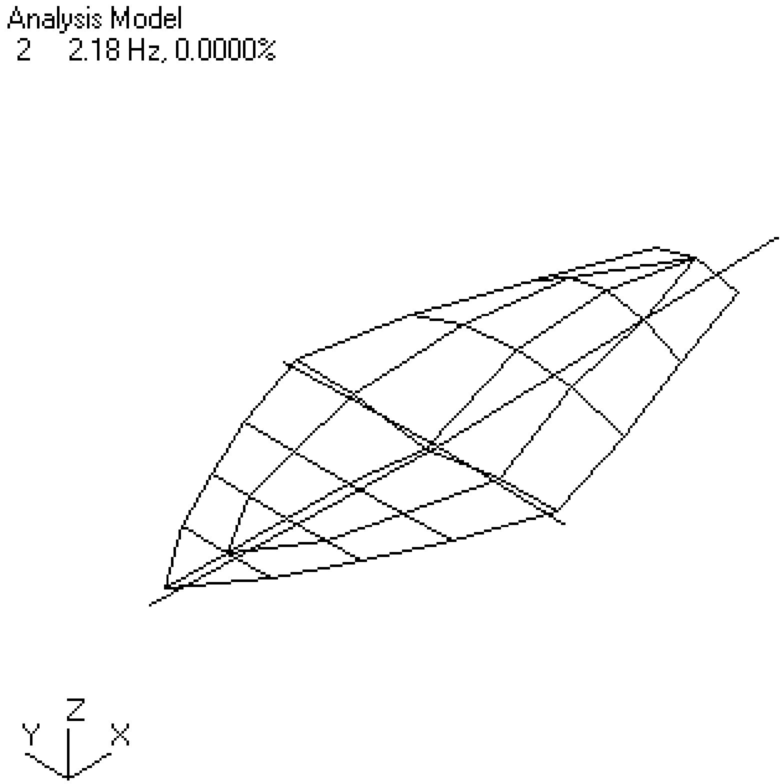
Frequencies and Mode Shapes

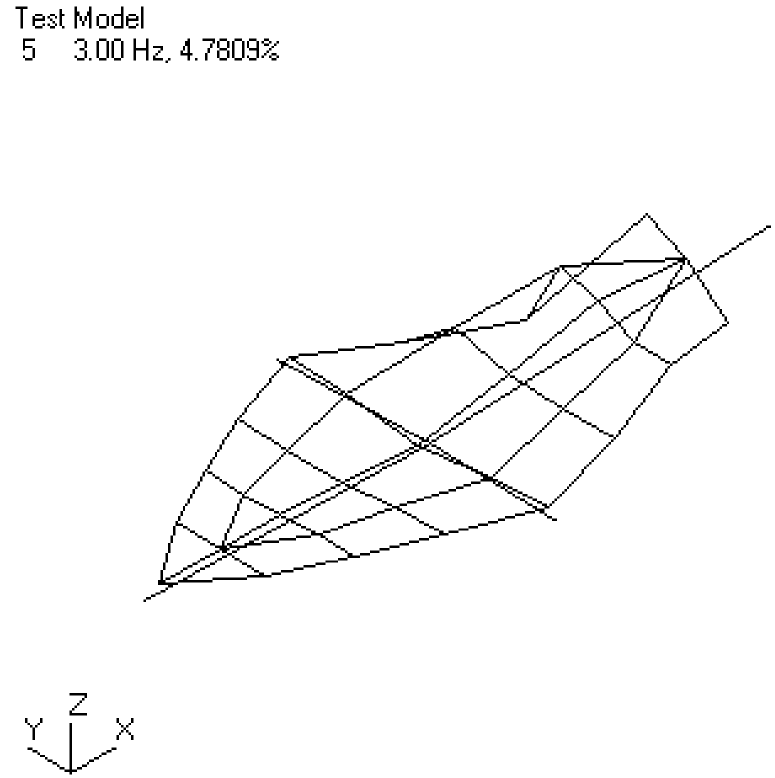
- Analysis / Test correlation performed using Dynaview software package
  - Analytical results for preload+gravity case
  - Test results from random excitation tests
  - Orthogonality calculation used to identify mode pairs
- In general, modes dominated by support tube response correlate better than modes dominated by membrane response.

Comparison of Predicted/Measured Frequencies (Short Side Down Orientation)

Predicted (Hz)	Measured (Hz)	Difference (%)	Description
2.18	3.00	-27.33	Membrane mode
3.55	3.48	+2.01	First bending mode of long tube
5.54	5.07	+9.27	First bending mode of medium tube
6.43	5.96	+7.89	Medium tube/short side of membranes

Mode Shape Correlation

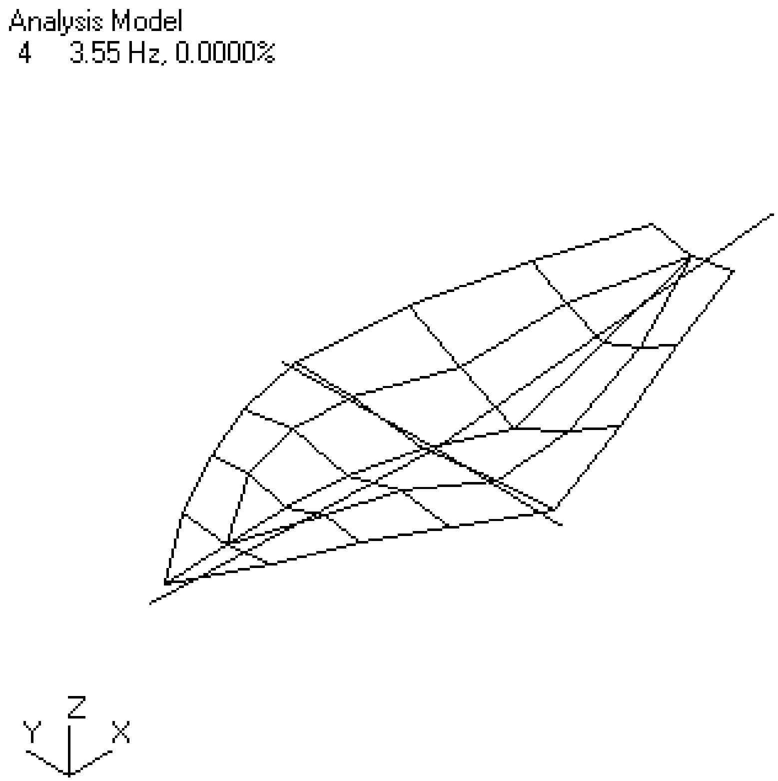


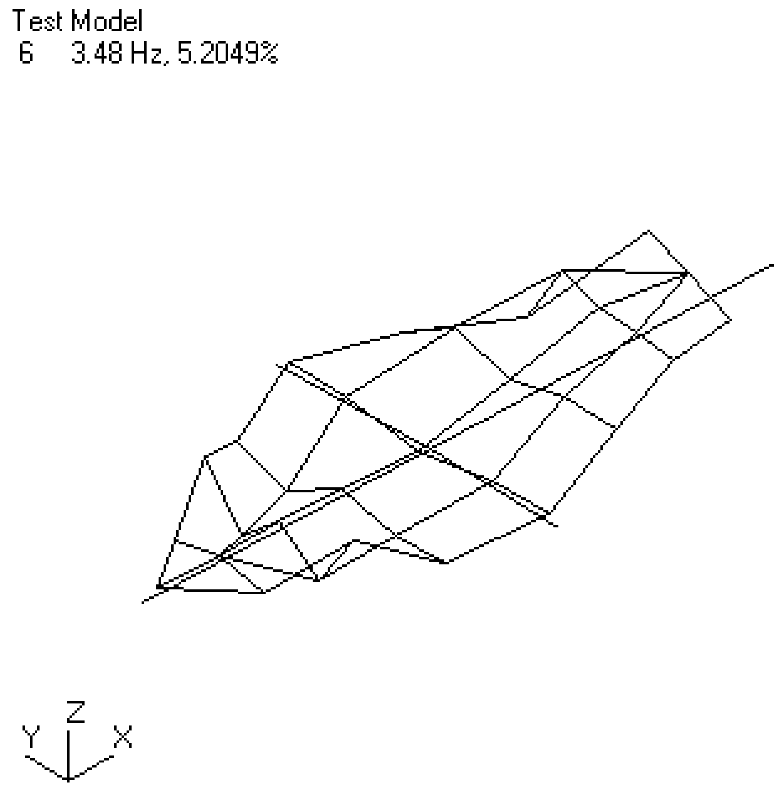


Mode Shape Animations

- Long side of membranes
- Long tube in-phase with membranes
- Frequency = 2.2 Hz (Analysis) / 3.0 Hz (Test)

Mode Shape Correlation





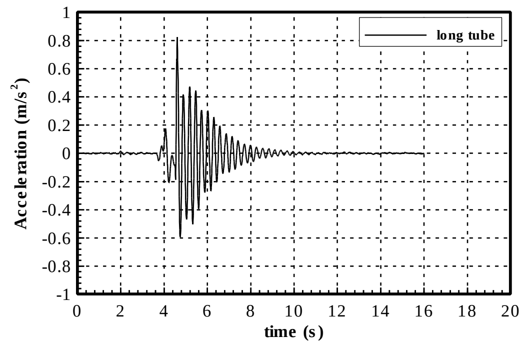
Mode Shape Animations

- First bending mode of long tube
- Long side of membranes out-of-phase with tube
- Frequency = 3.5 Hz (Analysis/Test)

Comparison of Analysis and Experiment

Impulse Test Simulation – Support Tube Response

<table>
<tr><th>Description</th><th>Predicted</th><th>Measured</th></tr>
<tr>
<td>(a) Time domain

Acceleration in z direction as a function of time at the tip of the long support tube.</td>
<td>
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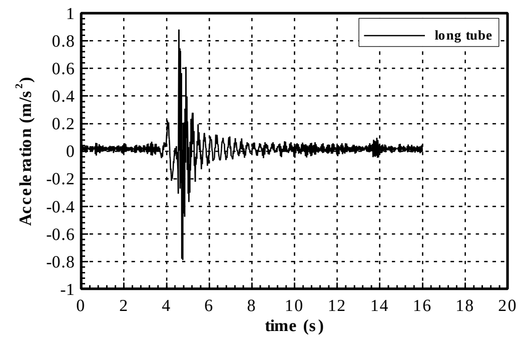
<td>
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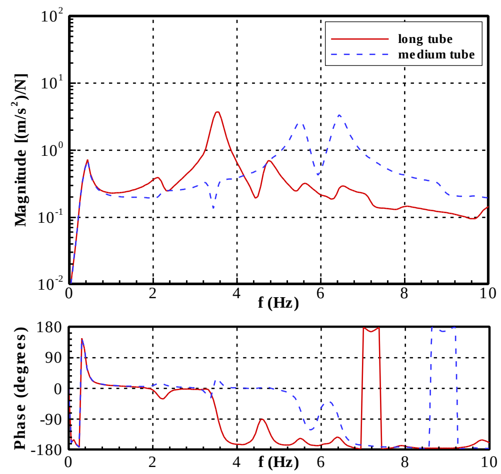
<td>(b) Frequency domain

Frequency response functions for tips of long and medium support tubes.

Input = drive point force
Output = acceleration of tube tips</td>
<td>
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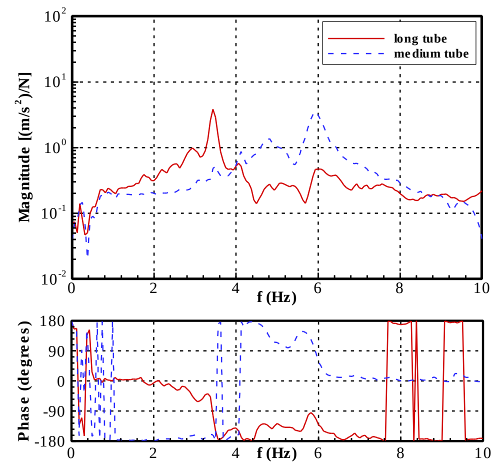
<td>
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Closing Remarks

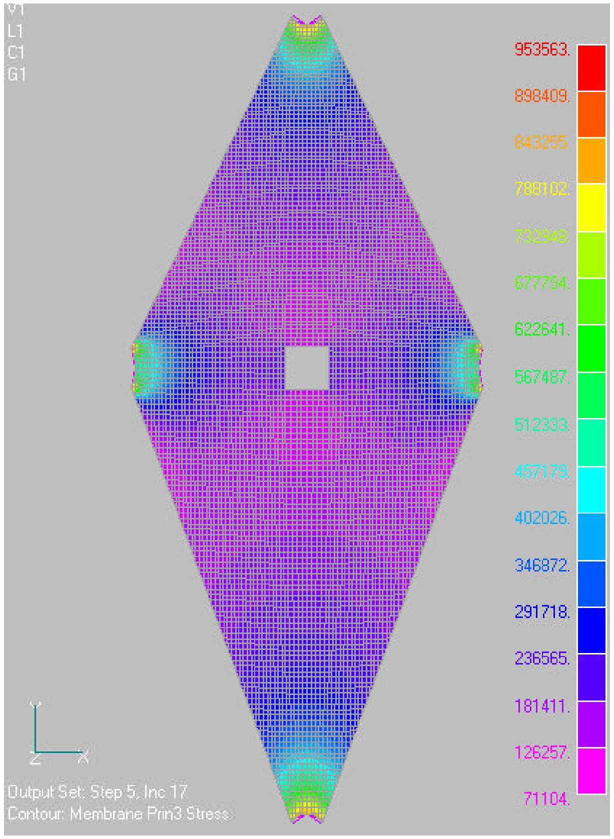
- Finite element analysis was used to predict the structural dynamic behavior of a one-tenth scale model of the NGST ‘yardstick’ concept sunshield.
  - Membranes modeled using approximate engineering technique that accounts for wrinkling effects.
  - Comparison of analytical predictions and test results showed good agreement for modes dominated by support tube motions, but only fair agreement for modes dominated by membrane response.

- Current / Future Work:
  - Development of a new membrane finite element model of the sunshield using “Iterative Membrane Properties (IMP)” method developed by Adler and Mikulas/U. Colorado-Boulder.
  - Follow-on testing of one-tenth scale model sunshield.

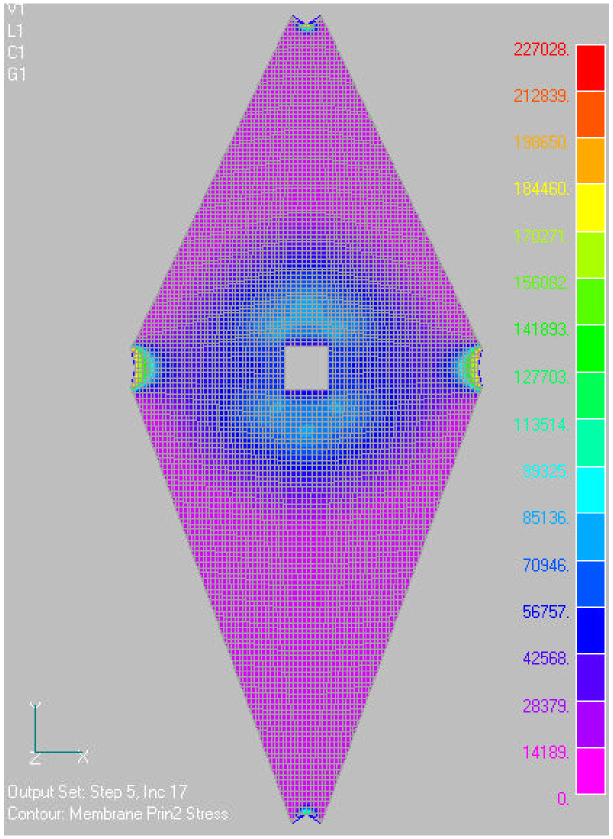
Current Work

Wrinkled Membrane FEA

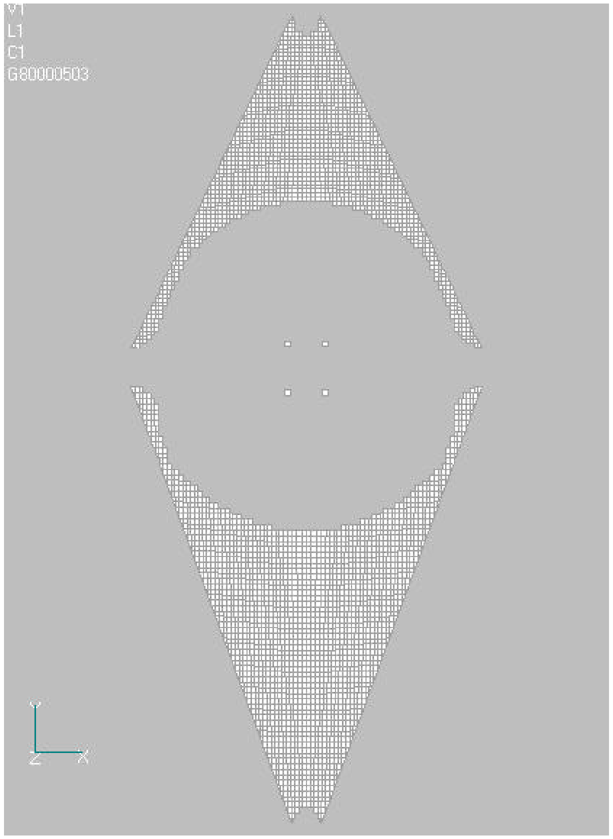
Major Principal Stresses



Minor Principal Stresses



Wrinkle Region



Membrane wrinkling effects modeled
using IMP method developed
by Adler and Mikulas/U. Colorado-Boulder